

THE SCATTERING OF LIGHT BY DIELECTRICS
OF SMALL PARTICLE SIZE

By

GEORGE F. A. STUTZ, JR.

A DISSERTATION SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES
OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

REPRINTED FROM THE JOURNAL OF THE FRANKLIN INSTITUTE,
VOL. 210, NO. 1, JULY, 1930.

THE SCATTERING OF LIGHT BY DIELECTRICS OF SMALL PARTICLE SIZE

By

GEORGE F. A. STUTZ, JR.

A DISSERTATION SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES
OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

REPRINTED FROM THE JOURNAL OF THE FRANKLIN INSTITUTE,
VOL. 210, NO. 1, JULY, 1930.



PRINTED IN THE U. S. A.

LANCASTER PRESS, INC.
LANCASTER, PA.

THE SCATTERING OF LIGHT BY DIELECTRICS OF SMALL PARTICLE SIZE.*

BY

G. F. A. STUTZ, Ph.D.

The diffusion of light by a cloud or suspension of relatively small particles of material may be due to:

1. Rayleigh scattering.
2. Reflection and refraction.
3. A combination of (1) and (2).

This paper presents the results of a study of the diffusion of light by a dielectric material (zinc oxide) in the range of particle sizes where, with increasing particle size, Rayleigh scattering rapidly diminishes while reflection and refraction effects become more and more important.

RAYLEIGH SCATTERING.

The theory of the scattering of light by small particles was first given by Lord Rayleigh.¹ Considering the case of a single particle of infinitesimal size compared with the wavelength of light, each particle acts as an oscillator undergoing forced vibrations of a certain amplitude in the direction of the impressed force. The particle, therefore, sends out waves whose vibrations are perpendicular to the direction of the incident light. The intensity of this scattered light is calculated by Rayleigh to be $I_s = \frac{Kd^6}{\lambda^4}$

Where K is a constant,

d = diameter of the particle,
 λ = wave-length of light.

* A Dissertation Submitted to the Johns Hopkins University in Conformity with the Requirements for the Degree of Doctor of Philosophy.

¹ "On the Blue Light from the Sky, Its Polarization and Colour," J. W. Strutt, *Phil. Mag.*, 41, 107 (1871).

Thus the intensity varies inversely as the fourth power of the wave-length of light and directly as the sixth power of the diameter of the particle. Moreover Rayleigh finds that at an angle of 90° from the direction of propagation of the light, the scattered light will be completely plane polarized.

REFLECTION AND REFRACTION.

In the case of particles large compared with the wave-length of light, the diffused light is due to reflection at the surfaces of the particle. In the case of a dielectric, this reflected light is almost independent of the wave-length (the change in refractive index with change in wave-length affects it slightly) and is proportional to the surface of the particle, thus $I_s = Kd^2$. No complete polarization is to be expected as in the case of the Rayleigh scattering. In considering particles of increasing size, a transition range must, therefore, be present between the very small, Rayleigh particles, where $I_s = \frac{Kd^6}{\lambda^4}$, the scattered light being polarized, and the large particles where $I_s = Kd^2$, with little or no polarization of the scattered light.

The more exact theoretical study of the intensity and polarization of the diffused light has been carried on by several investigators.² Shoulejkin,³ following the method of Mie, calculates that Rayleigh's formula holds for particles of diameter less than one-third the wave-length of light. For particles equal in diameter to the wave-length of light he calculates that the brightness of the light scattered in the direction of the incident beam is eleven times greater than the brightness in the opposite direction, and the maximum of polarization is displaced from 90° in the direction of the incident rays. For sizes greater than this, reflection only takes place.

According to Rayleigh's formula, the distribution of the light scattered in different directions is symmetrical about an axis perpendicular to the direction of propagation of the light.

² Mie, *Ann. d. Phys.*, **25**, 377 (1908). Debye, *Math. Ann.*, **67**, 540 (1909). Bromwich, *Roy. Soc. London (A)* **220**, 175 (1920). Schirmann, *Ann. d. Phys.*, **59**, 493 (1919). Gans, *Ann. d. Phys.*, **62**, 331 (1920); **76**, 29 (1925).

³ *Phil. Mag.*, **48**, 308 (1924).

This distribution becomes asymmetrical with increasing particle size, more light being scattered forward than backward, and Shoulejkin's calculations give the distribution, both of the total light and the polarized component for two particle sizes. H. Blumer⁴ has made a more elaborate and exact series of calculations, extending the work of Rayleigh, Mie, and Shoulejkin, and has determined the distribution of intensity of both the polarized and nonpolarized components of the scattered light for a large range of particle sizes as well as for several indices of refraction in the case of dielectric particles.

Recently, Pokrowski⁵ has described the "Opoloskop," an instrument for measuring the intensity of the light scattered at different angles by a suspension. He points out that by the use of Blumer's calculations, his instrument may be used to measure particle size. No actual measurements are given.

PREVIOUS INVESTIGATIONS.

Rayleigh's theory has received many experimental verifications (Crova,⁶ Zettwick⁷). Mechlenburg⁸ finds that in the case of sulfur, Rayleigh's formula holds for particles less than .100 micron in diameter; at .150 micron a transition begins which extends then from .250 micron to .850 micron; above .850 micron conditions again change but no relation is given. Between .250 micron and .850 micron, Mechlenburg finds that I is proportional to $1/\lambda^2$.

Bechhold and Hebler⁹ in measurements of the intensity of the Tyndall beam have a maximum intensity in the case of barium sulfate in water at .800 micron and consider that for particle sizes less than this Rayleigh's law holds. Later work by Owe¹⁰ in the same laboratory placed the maximum at about .2 micron.

⁴ *Zeit. Physik*, **32**, 119 (1925); **38**, 304 (1926).

⁵ *Koll. Zeit.*, **47**, 55 (1929).

⁶ *Am. Chim. Phys.*, **20**, 480 (1890); **25**, 534 (1892).

⁷ *Phil. Mag.*, **4**, 199 (1902).

⁸ *Koll. Zeit.*, **16**, 97 (1915).

⁹ *Koll. Zeit.*, **31**, 70 (1922).

¹⁰ *Koll. Zeit.*, **32**, 73 (1923).

MATERIALS STUDIED.

Zinc oxide is a white powder of exceptionally uniform particle size, made by the burning of zinc vapor with air. The oxide, being a fume product, is readily dispersed in water with the aid of saponin and gum arabic. Such suspensions are very stable, there is no growth of the particles on aging, and the high refractive index of zinc oxide, 2.01, makes it an ideal material from the standpoint of the amount of light it diffuses. The particular group of samples used includes several commercial samples and several that were specially prepared. The particle size of samples Nos. 5, 6 and 7 was measured by the photomicrographic method of Green,¹¹ while Nos. 1, 2, 3 and 4 were measured by the Stutz-Pfund turbidimeter.¹² This instrument was calibrated in this range of particle sizes by both the method of Green and the count method using a dark ground illuminator and counting chamber. The particle size figures are probably accurate to within five per cent. The samples have been selected as being the most uniform in particle size obtainable.

TABLE NO. I.

Sample No.	Particle Size in Microns.
1.....	.135
2.....	.192
3.....	.217
4.....	.282
5.....	.409
6.....	.676
7.....	1.23

EXPERIMENTAL WORK ON TURBIDITY.

For the accurate measurement of the average particle size of a material in suspension the Stutz-Pfund turbidimeter has been very successful in the range from .1 to 1.0 micron. This instrument records the amount of light transmitted by a suspension of the material contained in a cell three inches long, fitted with glass windows. A diagram of the instrument is shown in Fig. 1. The amount of parallel light from lamp L₁

¹¹ JOUR. FRANK. INST., 192, 637 (1921).

¹² J. Ind. Eng. Chem., 19, p. 51 (1927).

transmitted by the suspension in cell F is measured by means of the photometer device consisting of an optical pyrometer lamp L_2 with variable resistance and milliammeter E. The photometer device is readily calibrated by means of a rotating sector.

This instrument has been used to determine, in the case of zinc oxide suspended in water, the particle size at which

FIG. 1.

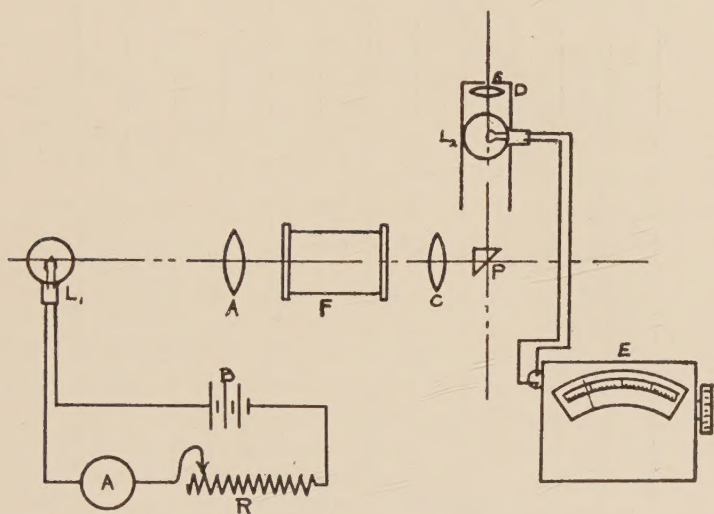
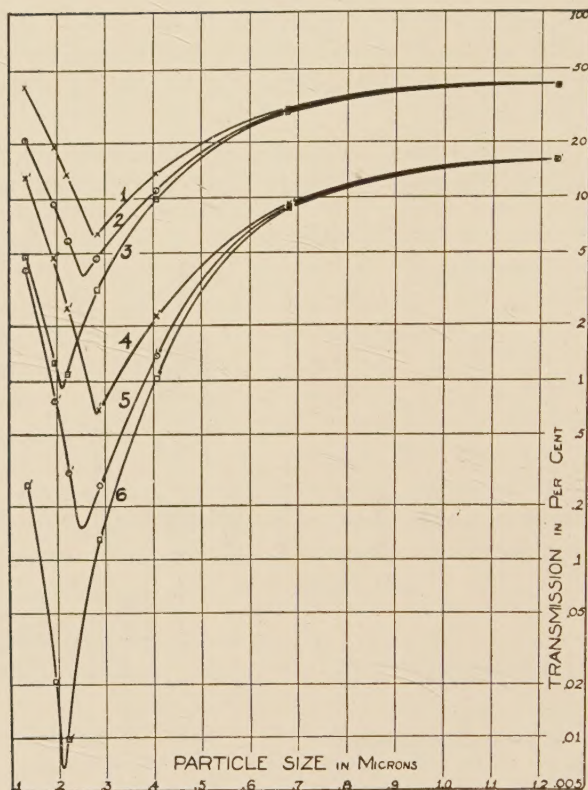


Diagram of the Stutz-Pfund turbidimeter.

the turbidity becomes a maximum (minimum transmission). In addition, the effect of the wave-length of the light used, as well as the effect of the concentration of the suspension has been studied.

For this purpose, suspensions of the samples listed in Table No. 1 were examined at two different concentrations and three glass color screens having fairly narrow spectral transmission bands were used in the photometer eyepiece. The dominant wave-length of transmission of these screens occurred at $6300 \text{ \AA}$ (red), $5500 \text{ \AA}$ (green), and $4800 \text{ \AA}$ (blue).

FIG. 2.



Curve 1—	Concentration	2.77×10^{-5}	gr. per cc.	wave-length	= 6300 Å.
Curve 2—	"	2.77×10^{-5}	" " " "	"	= 5500 Å.
Curve 3—	"	2.77×10^{-5}	" " " "	"	= 4800 Å.
Curve 4—	"	5.54×10^{-5}	" " " "	"	= 6300 Å.
Curve 5—	"	5.54×10^{-5}	" " " "	"	= 5500 Å.
Curve 6—	"	5.54×10^{-5}	" " " "	"	= 4800 Å.

Variation in transmission with particle size.

The results are shown in Fig. 2. From these results the following conclusions may be drawn:

1. Above one micron in particle size, the suspension transmits all wave-lengths of light equally. This indicates that in the range of particle sizes from one micron up, Rayleigh scattering is negligible. This is in agreement with the work of Tolman and his co-workers, and of Bechhold and Hebler.

- 2. Within the range studied the turbidity maximum is independent of concentration.
- 3. Turbidity maxima may be tabulated as follows:

TABLE NO. 2. .

Particle Size of Maximum.	Relative Particle Size.	Wave-length.	Relative Wave-length.
.21.....	1	4800	1
.25.....	1.19	5500	1.15
.275.....	1.31	6300	1.31

Therefore, within the range of wave-lengths studied, the particle size at which maximum turbidity occurs varies in direct proportion to the wave-length.

EXPERIMENTAL WORK ON DISTRIBUTION OF SCATTERED LIGHT.

Experimental determinations of the distribution of the intensity and polarization of the scattered light have not been extensively carried on. Most of the data recorded have been limited to the light scattered at a ninety degree angle, largely because of the apparatus difficulties involved.

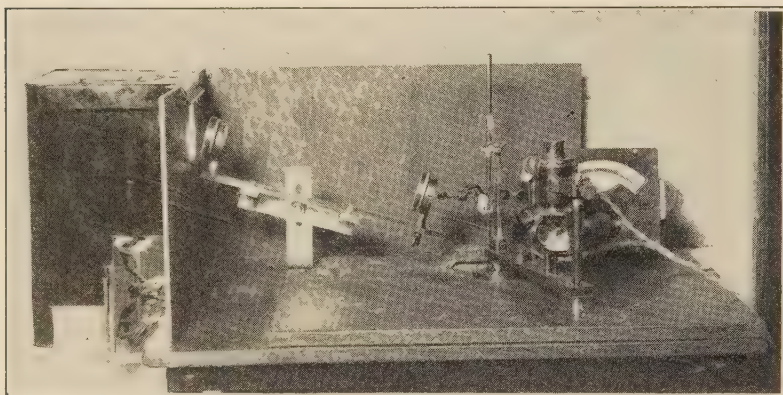
The calculations of the angular distribution of the light diffused by fine materials are based on a single particle, while any experimental determination must be based on a suspension of a large number of particles. Measurements on a large volume of a fairly concentrated suspension are very unsatisfactory due to the secondary scattering effects introduced by the successive depths or layers of particles. To overcome this difficulty as far as possible, a minimum volume of suspension has been used in the following work. A small volume may be examined experimentally by use of a capillary tube of large external diameter and fine bore.

APPARATUS.

A photograph of the apparatus used is shown in Figure 3, and a diagram in Fig. 4. The light source, L₁, was a 400 watt Pointolite tungsten filament arc lamp operating on a 110 volt direct current circuit. This gave a light of high, uniform intensity without which the work would have been impossible. Lenses F₁ and F₂ serve to focus an image of the lamp target

on the capillary tube C. The cell C is a glass capillary tube selected for freedom from bubbles and imperfections, with

FIG. 3.



Light scattering apparatus.

outside diameter 10 mm., inside diameter 1 mm. A photograph of the cell is shown in Figure 5. Stray light, which

FIG. 4.

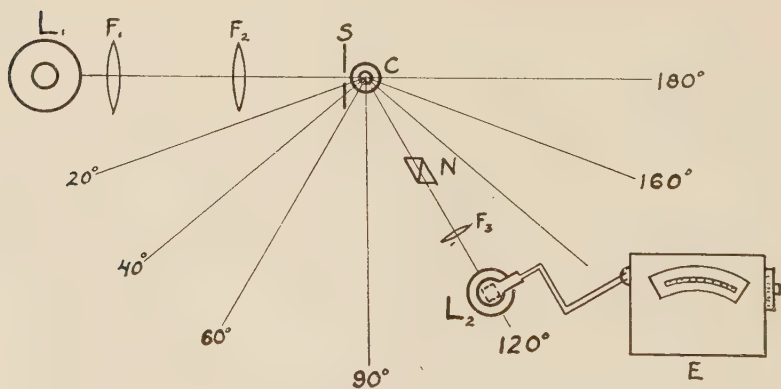


Diagram of the light scattering apparatus.

causes objectionable reflections, is excluded by means of the aperture S. The light scattered by the suspension in the cell is measured at various angles by means of a photometer

mounted on a movable, rotating carriage. This photometer includes a nicol prism, N , a lens F_3 to focus an image of the cell in the eyepiece, a total reflection prism, to reflect the light vertically upward, and an optical pyrometer eyepiece L_2 with

FIG. 5.

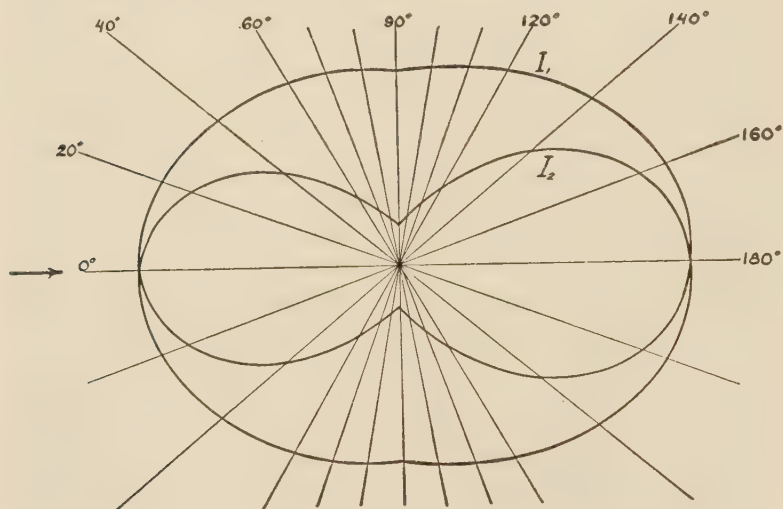


Photograph of the capillary tube cell.

variable resistance and milliammeter E . This photometer is calibrated by means of a rotating sector and using a magnesium carbonate block at C . The filament of the lamp L_2 is superimposed on the center of the image of the cell and, therefore, the light scattered from the center of the cell only is measured. In spite of the care used in designing the optical system to measure light from the center of the cell only, the cleanliness of the cell was found to be an important factor. The inside wall was cleaned thoroughly by scrubbing with concentrated nitric acid, then distilled water, then concentrated sodium hydroxide solution, and again with distilled water. This surface, once cleaned, would remain clean if the cell was kept filled with distilled water. To prevent scattering of light from the minute scratches, as well as dirt, on the outer wall of the cell, a thin

layer of cedar oil was brushed on. This successfully prevented any scattering whatever from the outer wall. To prevent the light directly reflected from the cell walls from entering the photometer eyepiece, it was necessary to place the light beam at a slight angle to the horizontal, as is shown in Fig. 3. This introduces a slight error in the angle at which the scattering

FIG. 6.



Distribution of light scattered by gold sol. (Diameter less than .10 micron.)

is measured. This has not been corrected for, the distribution being given for angles in a plane perpendicular to the cell. The effect of this angle is too slightly fore-shorten the distribution diagrams.

To determine the degree to which the apparatus approached the ideal, use was made of a fine gold suspension. While no direct measurement of the particle size of this material was made, its appearance (very faint turbidity with clear red color) indicates that it is well below .10 micron, and should have a symmetrical distribution of the scattered light. The results obtained on this sol are plotted in Fig. 6. The distribution is very nearly symmetrical; the asymmetry appears to be due to the effect of illuminating the cell at a slight angle, instead of perpendicularly, since illuminating at a greater angle results in a more asymmetrical distribution. The approach to

symmetrical distribution is considered sufficiently close to justify the use of the apparatus in a further study of the angular distribution of scattered light.

In plotting the results given in Fig. 6, the two intensity components of the light, I_1 and I_2 , are the two components vibrating at right angles to one another, obtained by placing the nicol prism N in the two positions ninety degrees apart.

A slight correction may be made for the scattering present in pure distilled water. This correction is so small that it has been neglected in all cases except that of the gold sol given above, when the intensities were so low as to make this factor of some importance.

RESULTS OBTAINED.

The results obtained on the seven samples of zinc oxide, determined at a concentration of 1.39×10^{-4} grams per cc., with water as the suspending medium, are tabulated in Table No. 3. A red color screen ($\lambda = 6300 \text{ \AA.}$) was used in the eye-

TABLE No. 3.

No. 1. $d_1 = .135$. Wave-length = $6300 \text{ \AA.}$

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	.54	.54	100	.710	.15
40.....	.375	.25	110	.810	.25
60.....	.405	.132	120	1.11	.51
70.....	.445	.080	140	2.20	1.33
80.....	.510	.088	160	5.35	4.9
90.....	.580	.088	180	9.2	9.2

No. 2. $d_1 = .192$. Wave-length = $6300 \text{ \AA.}$

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	.71	.73	100	.81	.15
40.....	.54	.35	110	.97	.27
60.....	.48	.18	120	1.42	.62
70.....	.51	.12	140	2.62	1.82
80.....	.58	.088	160	6.05	5.35
90.....	.66	.096	180	12.5	9.2

No. 3. $d_1 = .217$. Wave-length = 6300 Å.

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	1.11	1.11	100	.87	.231
40.....	.71	.48	110	1.11	.35
60.....	.54	.27	120	1.51	.66
70.....	.58	.212	140	3.42	2.62
80.....	.62	.162	160	8.6	8.3
90.....	.66	.162	180	14.0	14.5

No. 4. $d_1 = .282$. Wave-length = 6300 Å.

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	1.61	1.64	100	.97	.51
40.....	.81	.66	110	1.11	.71
60.....	.66	.445	120	1.72	1.10
70.....	.54	.375	140	3.25	2.62
80.....	.58	.375	160	13.0	9.2
90.....	.66	.405	180	24.0	24.0

No. 5. $d_1 = .404$. Wave-length = 6300 Å.

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	1.10	.81	100	.66	.51
40.....	.445	.405	110	.76	.62
60.....	.445	.375	120	.97	.97
70.....	.48	.325	140	2.2	2.2
80.....	.48	.375	160	6.6	7.4
90.....	.51	.405	180	14.5	13.5

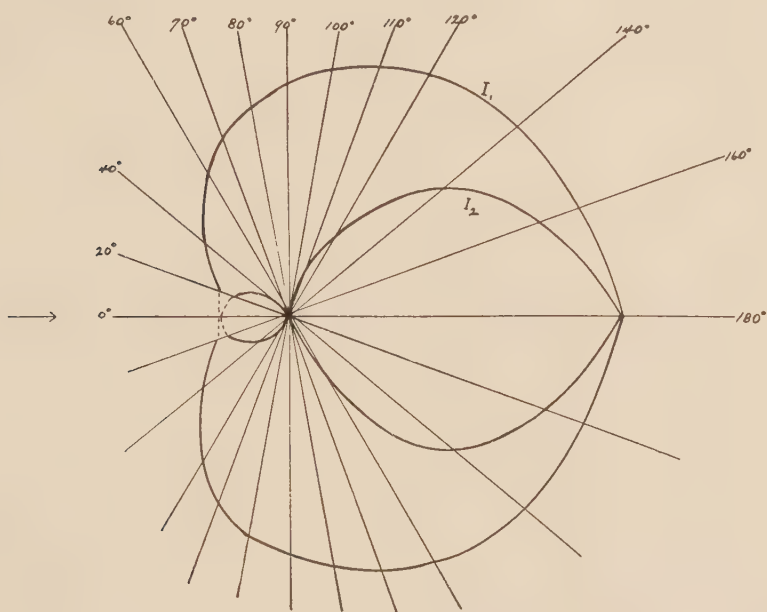
No. 6. $d_1 = .676$. Wave-length = 6300 Å.

Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	.81	.87	100	.35	.35
40.....	.325	.325	110	.445	.445
60.....	.30	.30	120	.58	.58
70.....	.30	.25	140	.97	.97
80.....	.30	.27	160	2.95	2.5
90.....	.325	.30	180	8.9	9.2

No. 7. $d_1 = 1.23$. Wave-length = 6300 Å.

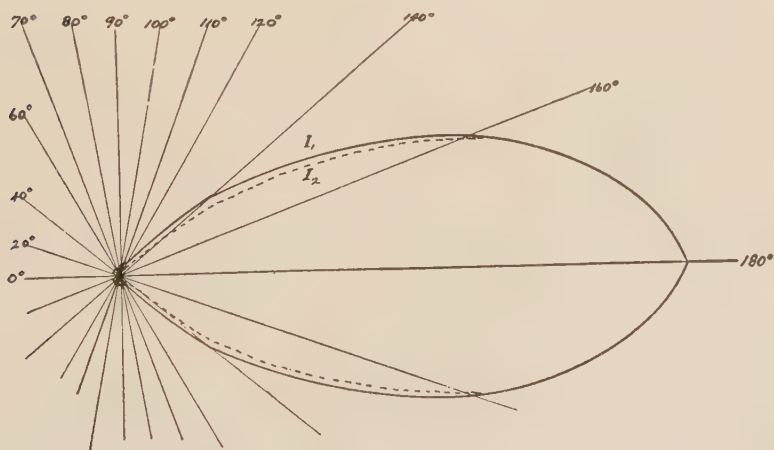
Angle.	I_1 .	I_2 .	Angle.	I_1 .	I_2 .
20.....	.48	.51	100	.27	.325
40.....	.325	.27	110	.375	.375
60.....	.25	.23	120	.48	.45
70.....	.25	.25	140	.81	.81
80.....	.212	.23	160	2.08	2.08
90.....	.27	.27	180	6.6	6.3

FIG. 7.



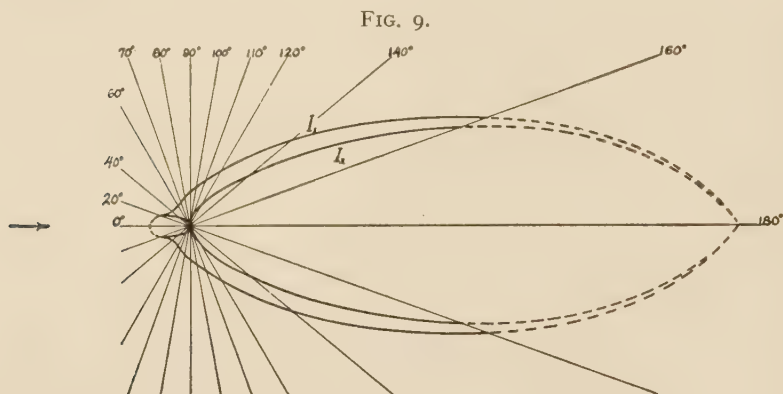
Distribution from a single particle as determined by extrapolation of calculations by Blumer.
 $d_1 = .135$ micron wave-length = $6290 \text{ \AA}$.

FIG. 8.



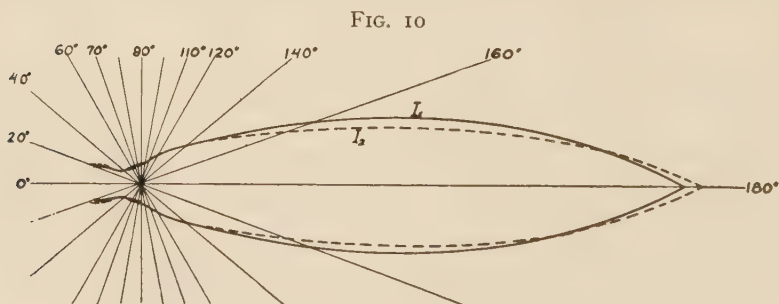
Distribution from a single particle as determined by extrapolation of calculations by Blumer.
 $d_1 = .676$ micron wave-length = $6290 \text{ \AA}$.

piece. Similar results have also been obtained using the green and blue color screens. The red screen, with the type of photometer used, gives the best color match and consequently the most accurate results; therefore, only the red readings will be considered in detail.



Observed distribution from a suspension $d_1 = .135$ microns wave-length = $6300 \text{ \AA}$.

The distributions from single particles, at sizes .135 micron and .676 micron, as extrapolated from the calculations of Blumer are given in Fig. 7 and Fig. 8. Corresponding ob-



Observed distribution from a suspension $d_1 = .676$ wave-length = $6300 \text{ \AA}$.

served distributions from suspensions, at sizes .135 micron and .676 micron are given in Fig. 9 and Fig. 10. It is at once evident that the tremendous difference in ratio of forward scattering to backward scattering, as calculated for different particle sizes, is not actually observed.

From the calculated figures the ratio of the forward scattered light to that scattered backward, or at ninety degrees, changes rapidly over the range of particles here considered. Several of these ratios, together with the observed ratios, are tabulated in Table No. 4. The observed ratios do

TABLE No. 4.
Relative Total Intensities $I_1 + I_2$.
Wave-length = 6300 Å.

Particle Diameter d_1 .	Ratio of Total Intensity 160°/90°.		Ratio of Total Intensity 160°/20°.	
	Calculated.	Observed.	Calculated.	Observed.
.135	2.39	15.3	4.26	9.5
.192	2.90	15.1	2.72	7.8
.217	3.07	20.5	2.58	7.6
.282	5.10	20.8	8.2	6.25
.404	13.4	15.3	30.7	7.3
.676	37.6	8.7	34.4	3.24
1.23	48.0	7.7	29.3	4.2

not have the large changes indicated in the calculated results and are reversed in order of magnitude. A careful study of the effect of mixtures of zinc oxide of various sizes and of the effect of concentration, failed to indicate any error great enough to explain the lack of agreement.

DEPOLARIZATION.

Gans¹³ has pointed out the significance of a figure which he calls the degree of depolarization. It is defined as:

$$\theta = \frac{I_2}{I_1 - I_2}.$$

B. Lange¹⁴ has applied the depolarization to measurements on various sols and shown a fair agreement with the calculated data of Blumer. The depolarization calculated from the figures of Blumer is tabulated in Table No. 5, as well as the observed value for the ninety degree angle, calculated from the values given in Table No. 3. While the observed values do not check the calculated figures exactly, it is seen that the

¹³ *Am. Physik.*, 37, 881 (1912); 62, 33 (1920).

¹⁴ *Zeit. Phys. Chem.*, 132, 1 (1928).

general trend and the order of magnitude are the same. The calculated results range from zero through infinity to negative values while the observed results range from .179 to infinity.

TABLE No. 5.
Depolarization.
Angle -90° .

Particle Diameter d_1 .	Calculated (Blumer) $\lambda = 6290 \text{ \AA.}$			Observed $\lambda = 6300 \text{ Conc.} = 1.38 \times 10^{-4} \text{ gr./cc.}$		
	I_1 .	I_2 .	θ	I_1 .	I_2 .	θ .
.135	.0075	.0000	.000	.58	.088	.179
.192	.062	.0001	.001	.66	.096	.170
.217	.125	.0008	.006	.66	.162	.27
.282	.340	.015	.046	.66	.405	2.61
.404	.600	.610	-61.	.51	.405	3.86
.676	1.30	3.10	-1.72	.325	.30	12.00
1.23	2.40	3.00	-5.0	.27	.27	

Lange has pointed out the fact that to obtain θ , only the ratio I_2/I_1 is needed. If φ is the angle which the resultant of the two amplitudes makes with the one component,

$$\frac{I_2}{I_1} - = \tan^2 \varphi$$

and

$$\theta = \frac{\tan^2 \varphi}{1 - \tan^2 \varphi}.$$

The determination of φ requires a much simpler procedure than the determination of I_1 and I_2 , and the instrument was modified for this purpose. The nicol prism and photometer eyepiece were removed and replaced by an optical system consisting of a slit, a fixed Wollaston prism, and a rotatable nicol prism. The Wollaston prism forms two images of the cell, corresponding to the two directions of vibration of the light. The angle φ is obtained by rotating the nicol until the two images appear equal in intensity.

One series of observed values of φ obtained on the modified apparatus and the corresponding values of θ are recorded in Table No. 6. A negative value for θ indicates an angle greater than 45° , or I_2 greater than I_1 .

TABLE NO. 6.
*Depolarization (Observed).*Angle = 90°. Wave-length = 6300 Å. Concentration = 2.78×10^{-5} grams per cc.

No.	Particle Diameter d_1 .	φ .	$\tan^2$.	θ .
1	.135	20.2	.135	.16
2	.192	19.2	.121	.14
3	.217	23.5	.19	.24
4	.282	35.6	.51	1.04
5	.404	39.2	.662	1.96
6	.676	41.1	.76	3.16
7	1.23	42.4	.833	5.00

Gans has pointed out that θ varies with the concentration and derives the relation:

$$\frac{\theta - \theta_0}{1 + \frac{5}{3}\theta} = 2aC,$$

where θ_0 is the depolarization at zero concentration, therefore, for a single particle,

C is a constant proportional to the concentration,
 a is a constant dependent on the shape of the particles.

Lange extends this so that if the values of θ_1 and θ_2 at two concentrations c_1 and c_2 are determined, θ_0 may be calculated as:

$$\theta_0 = \frac{\frac{c_1}{c_2}\theta_2\left(1 + \frac{5}{3}\theta_1\right) - \theta_1\left(1 + \frac{5}{3}\theta_2\right)}{\frac{c_1}{c_2}\left(1 + \frac{5}{3}\theta_1\right) - \left(1 + \frac{5}{3}\theta_2\right)}$$

Using this relation, the value of θ_0 has been calculated from the observed values of θ at two concentrations and the results are recorded in Table No. 7. The values should correspond to those calculated from Blumer's data and the agreement is shown by the plot in Fig. 9. θ_0 does not have zero value at small particle sizes and it begins to increase rapidly for somewhat smaller sizes than in the case of Blumer's figures. The general shape of the curve, however, is the same.

Differences may be partly attributed to error in particle size determination, to the non-uniformity of particle size, and to the shape of the particles. Blumer's figures are based on spherical particles, while the zinc oxide particles are at best only approximately spherical in shape.

TABLE No. 7.
Depolarization θ_0
Calculated from Observed θ
Angle = 90° Wave-length = 6300 Å.

Particle Diameter d_1 .	θ_1 at Concentration 2.78×10^{-3} gr. per cc.	θ_2 at Concentration 1.39×10^{-4} gr. per cc.	θ_0 .	θ Calculated (Blumer).
.135	.16	.18	.09	.00
.192	.14	.22	.12	.001
.217	.24	.29	.23	.006
.282	1.04	1.18	1.01	.046
.404	1.96	5.30	1.65	-61.0
.676	3.16	7.85	2.70	-1.72
1.23	5.00	-4.57	2.90	-5.0

The values of θ obtained with mixtures of two of the pigments indicate that this factor may be of value in determining the amount of fine and coarse material in a specimen of zinc oxide. At the concentration 1.39×10^{-4} grams per cc. the value of θ for No. 1 is .174 and for No. 6 is 7.85. Ten per cent. by weight of No. 6 added to No. 1 gives $\theta = 1.02$ and fifty per cent. gives $\theta = 6.7$. This indicates that the failure of samples 1 and 2 to approach a zero value for θ may be due to their having two to three per cent. of large particles or aggregates.

SUMMARY.

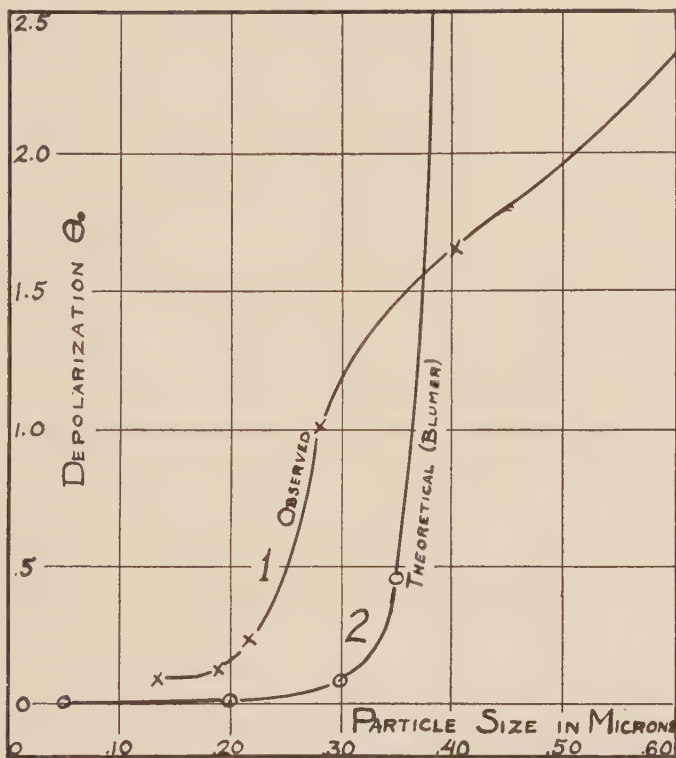
1. The turbidity maximum for zinc oxide dispersed in water is determined for three wave-lengths of light. The maximum occurs at .25 micron for wave-length 5500 Å.

2. The turbidity maximum occurs at smaller particle sizes for shorter wave-lengths. The particle size of maximum turbidity is found to be proportional to the wave-length of the light in the range of wave-lengths from 4800 Å. to 6300 Å.

3. An apparatus is described for determining the angular distribution of the light scattered by a suspension of fine particles.

4. The total intensity of the scattered light as observed does not have the same distribution as the calculated values of Blumer.

FIG. II.



Depolarization % calculated from results of Blumer, and from observed figures.

5. The depolarization, $\frac{I_2}{I_1 - I_2}$, as observed, follows the general trend of the theoretical values.

The author is indebted to Dr. A. H. Pfund for his help and many timely suggestions, particularly that of using a capillary as the cell; to Professor K. F. Herzfeld for his interest and help with the theoretical considerations; and to Mr. G. S. Haslam for his great assistance in setting up the apparatus and making the observations.

BIOGRAPHICAL NOTE

George Frederick Adelbert Stutz, Jr., son of George Frederick Adelbert and Wilhelmina (Fey) Stutz, was born at Washington D. C., on June 3, 1900. He graduated at the McKinley Manual Training School of Washington, in 1918, receiving the District of Columbia scholarship to Lehigh University. He was graduated from Lehigh University in 1922 with the degree of Chemical Engineer (Ch.E.). He pursued the course of graduate instruction in the Physics Department at the Johns Hopkins University during the years 1922-23, 1923-24, and 1927-28. In June, 1924, he was awarded the degree of Master of Arts (A.M.). When not engaged in university work, he has been employed as a Research Investigator in the Pigment Physics Laboratory of the Research Division of The New Jersey Zinc Company.

